



Solar Energy Technologies Program Multi-Year Technical Plan Review Presentation

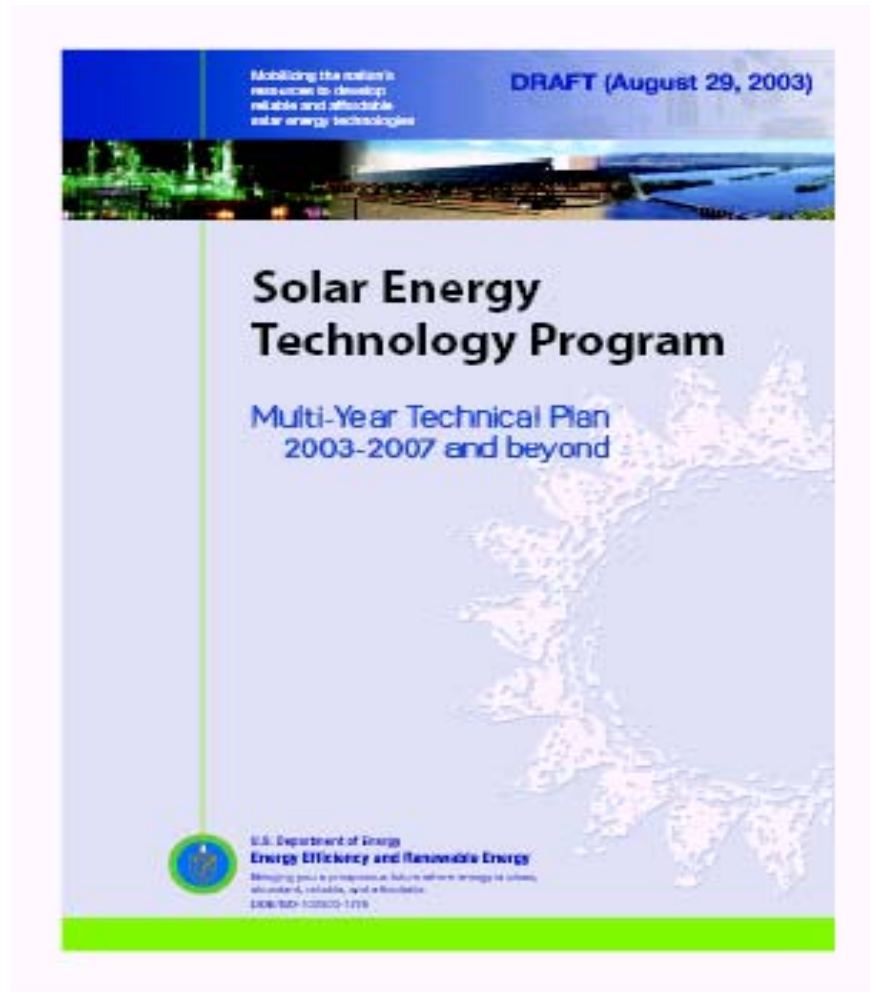
Jonathan W. Hurwitch
Senior Vice President
SENTECH, Inc

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Solar Energy Systems Symposium
October 16, 2003



U.S. Department of Energy
Energy Efficiency and Renewable Energy

First Integrated Solar MYTP



<http://www.nrel.gov/extranet/techplan/techplan.html>



Solar MYTP “Team”

Charles Hanley	(Sandia)
Mark Mehos	(NREL)
Kevin DeGroat	(McNeil Technologies)
Chris Cameron	(Sandia)
Tex Wilkins	(DOE-HQ)
Paul Klimas	(Sandia)
Ed Witt	(NREL)
Bob McConnell	(NREL)
Jon Hurwitch	(Sentech)
Bryan Pai	(Sentech) support



Section 1.0

National Perspective

Section 2.0

Industry, Markets, Applications

Section 3.0

Systems-Driven Approach

Section 4.0

Technical Sections

Section 5.0

Managing the Solar Energy Program

1.0 National Perspective

DRAFT 48/15/03

Solar Energy: A Nation

1.0 Solar Energy: A National Perspective

Solar energy is actually abundant, renewable energy source that can benefit the nation by diversifying our energy supply. Solar energy holds considerable long-term potential to reduce our dependence on imported fuels, improve the quality of the air we breathe, and to stimulate the economy by creating jobs in the manufacturing and installation of solar systems.

The following are key drivers for pursuing greater use of solar energy:

- Solar technology provides electricity, heating, cooling, and daylighting, and an overall need to produce hydroelectricity in such a transportation fuel for the future.
- Solar energy is the most plentiful and widely available form of renewable energy to be used to meet our energy needs for the world.
- Solar energy is the origin for all material energy for us, and we must need to use only as much solar energy as being displaced, as long as the sun continues to shine.

Using concentrated solar technology, we can get one mile by two miles by one square mile in the southern states lined down a cold power source as much energy as the entire nation currently consumes on an annual basis. To put the land area in context, an acre square mile of Mojave desert would be needed. Though generating all the electricity we need via solar energy is not the goal of the Solar Energy Technology Program of the U.S. Department of Energy (DOE), it does show that solar has the potential to be a significant part of a national nuclear energy portfolio.

[illegible]

In the near term, solar energy will reduce demand for natural gas used by utilities to generate electricity or used in buildings for space, water, and process heat. This is called natural gas substitution, which is environmentally desirable, and the displaced gas can be used in its highest-value applications, which include petrochemical processing, transportation fuels, and chemicals, while displacing air pollutants and greenhouse gases.

Further, these films, when energy could produce hydrogen peroxide transparently, chemically, and electrically, and so we can store energy in the form of hydrogen peroxide.



Solar Energy: A National Perspective

N&D 100 Awards

Research sponsored by the DOE Solar Energy Research Program has produced more than 40 papers and received numerous awards. R&D Magazine presents the prestigious R&D 100 awards annually to the top 100 research breakthroughs for that particular year. The DOE Office of Energy Efficiency and Renewable Energy has received more than 100 R&D 100 awards—more than any other agency other than NASA. Some that are private company success: Sun Microsystems, and more than any single company in the world since its inception, Intel, total more than 100 of the 100 awards over years to the Solar Process, including:

- | | |
|------|---|
| 2000 | Copper Indium Chloride Solar Cell |
| 2000 | Voltage-Induced Secondary Ion Mass Spectrometry |
| 2000 | Spontaneous Scanning Tunneling Microscopy |
| 2000 | Balium Indium Phosphate/Gallium Arsenide Solar Cell |
| 2000 | Cadmium Nitride Photodiode Modules |
| 2000 | Resonant Raman Microscopy |
| 2000 | Stress Determination of Hair and Organic Materials in <i>in situ</i> Mode |
| 2000 | Scanning Diffraction Mapping Systems |
| 2000 | Red-Staining Systems |
| 2000 | Acoustic Imaging Tech |
| 2000 | High-Pressure Phase-Change Disk Storage of Solid Colloids |
| 2000 | UV-Visible "Software Light-Trapping Model for Solar Cells |
| 2000 | UV SERS: Yttrium-Aluminum Garnet/Aluminum Nitride Thin-Film Modules |
| 2000 | Solar-to-Solar Junctions: A Light-Emitter for a Two-Photon Process in Multilayers |
| 2000 | High-Pressure Growth of Carbon Nanotube Solar Cells |
| 2000 | Power-Airflow Sensor: Compact Phase-Change Modules |

Near-Term Goals: The 2008 goal is to increase use of solar panels by a factor of six.

- Electrophoresis from phenol that separates nucleic acids
- Polymerase chain reaction (PCR) is used to amplify a specific DNA sequence
- Electrophoresis from agarose gels separates DNA fragments

[illegible]

Strategy

The Solar Program's strategy is to develop a community.

- Electric power for applications in the residential sector: mobile phones, single-family homes, urban
- Sunlight for illumination in the domestic sector
- Thermal energy for space heating, underfloor heating, domestic water heating
- Combination of electric, solar thermal and

The Programme implements this strategy using a solid analytical foundation based on an accreditation.

- What drives business and consumer markets?
- How do energy markets operate?
- What are the policy implications of these markets?

Solar Energy

Solar Energy: A National Perspective

DRAFT (B/15/03)

As the program is used, anyone who tries to approach the topic in a more narrow manner than that impact the B. For example, all values are based on targeting, control and are based on the "first point" shown under assumptions about the value of dispute liability and the cost of uncertainty in the market. Applications are given in a building with or without a close relationship with the market, such as a building with or without a close relationship with the market, such as a building with or without a close relationship with the market.

At the technology level, a systems-driven approach can help identify common research concerns, avoid duplication of effort, and place new advances in an area such as submerses might change the assumptions or requirements for sensors, applications, and real-time.

A national program to advance energy efficiency will make these specific actions to improve energy strategies, understand new laws, analyze policies, and work in partnership with state holders who purchase and improve solar energy systems into the U.S. energy strategy. These specific actions are presented in the following sections of the DOE Solar Energy Technology Program Multi-Year Technical Plan.

Solar Power Goes Mainstream

FV power is showing signs of going mainstream. After meeting the owner in the San Diego, California, area in September 2007, The Horse Depot® expanded the number of rooms being rented to include electric power options, as well as the geographic locations where these rooms are located.

By August 2002, Home Depot® stores were selling and installing PV systems under its "Go-Home Solar" program. In addition to its stores in green San Diego and in the Los Angeles metropolitan area, it throughout Long Island, New York, New Jersey, and four in Delaware were providing and service. The Home Depot® is worth financing options: The Home Depot® Co. and The Home Depot® Home Improvement

Funded by generous state rebates, a number of builders in California are building net-zero-power residential communities. A few of these progressive home builders in California that offer solar electric power as a standard feature are: Cloward Homes in Vista/Maricopa in Watsonville, Shambaugh & Vint in Palo Alto, Freeman Homes in Walnut Grove, Strickland, Standard Pacific Homes in San Diego, and US Home in El Cerrito and in Placerville/Coalinga. Additionally, Shambaugh offers both solar electric power and solar thermal water heating.



spore into standard features in Scripps Highback cross members in San Diego. Horsebuckler's out from Chorus Horns and She a Horns are now working with DDE 12 and 6 energy Horns to make a new energy with a new work back energy and work on a new long-term goal of a new energy use closer to the source of power.

The purpose of the Richford Ranch community will be the largest solar and wind solar project in the country, with PV installed on garages, community clubhouses, and main service buildings. The plan also allows for siting of solar towers to participate in the current district PV program. Total peak energy production from the Richford Ranch solar power system is projected to be a guide to 3.5 megawatts per year.

Multi-Year Technical Plan

Solar Energy Technology Program



2.0 Industry, Markets, and Applications

Major Themes:

Table 2-1. Solar Technologies and their Applicability to Various Market Sectors

•National

•Commercial

•Distributed

•Energy

•Existing

•Existing

•Solar Systems Descriptions and Requirements

		Distributed Energy			Central Generation	Fuels and Chemicals
		Building-Integrated	Ground-Mounted	Off-Grid		
PV	One-Sun	●	●	●	●	●
	Concentrating		●	●	●	●
Thermal	Dishes		●	●	●	●
	Towers				●	●
	Troughs	● ●	● ●		●	
	One-Sun Thermal	●	●	●		
	Air ^a	●				
	Passive Solar ^a	●				
	Hybrid Lighting	●				

^aDOE Solar Energy Technology Program does not conduct research in thermal air and passive solar collectors, and these technologies are not discussed further in this plan.

● Electrical Generation ● Thermal ● Solar Lighting ● Transportation

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What is the Systems Driven Approach?

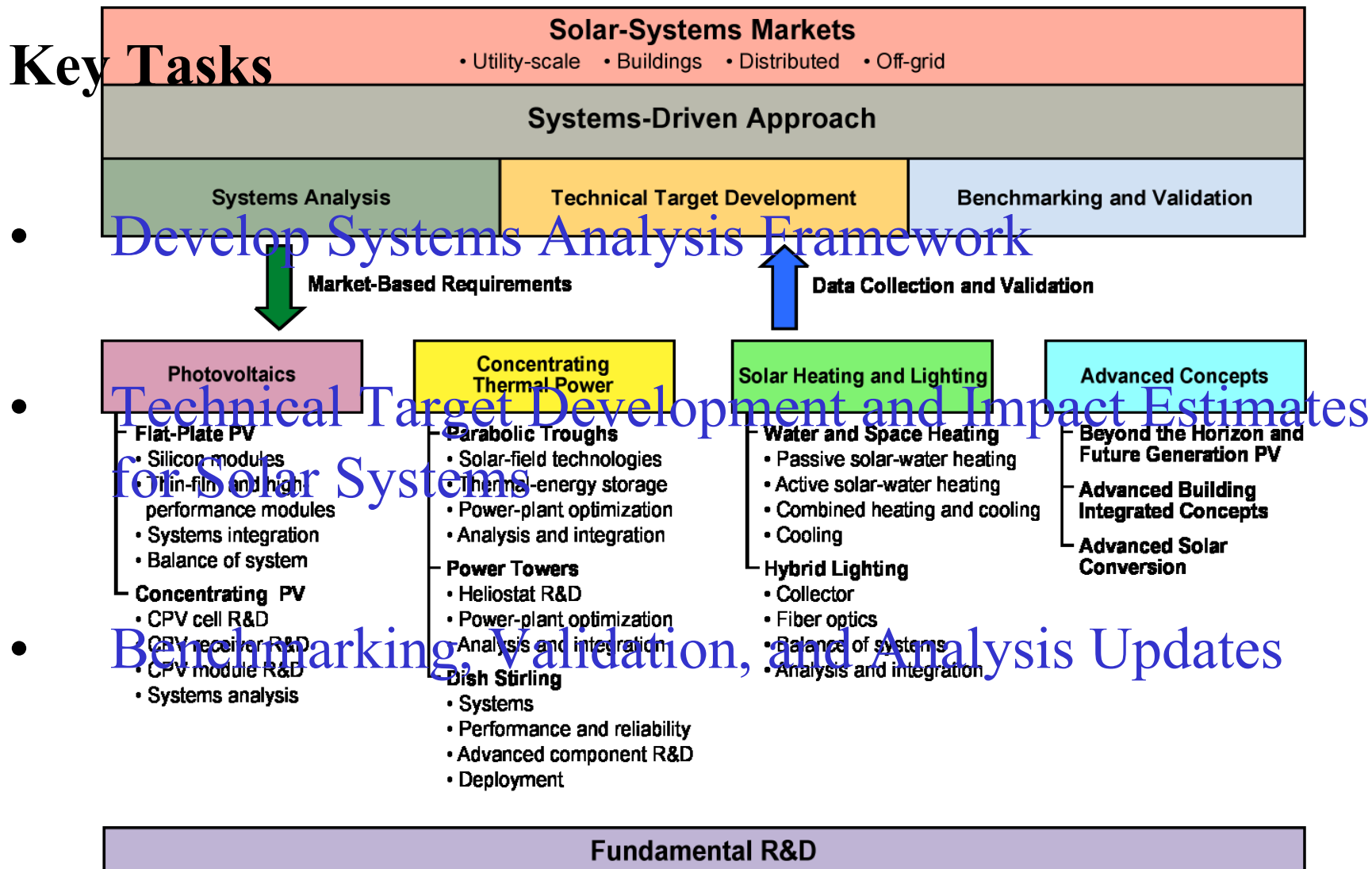
Definition:

All technical targets for R&D on the components and systems funded through the Solar Energy Technology Program are derived from a common market perspective and national energy goals, and the resultant technologies are tested and validated in the context of established criteria for each market.



3.0 Systems Driven Approach

Key Tasks





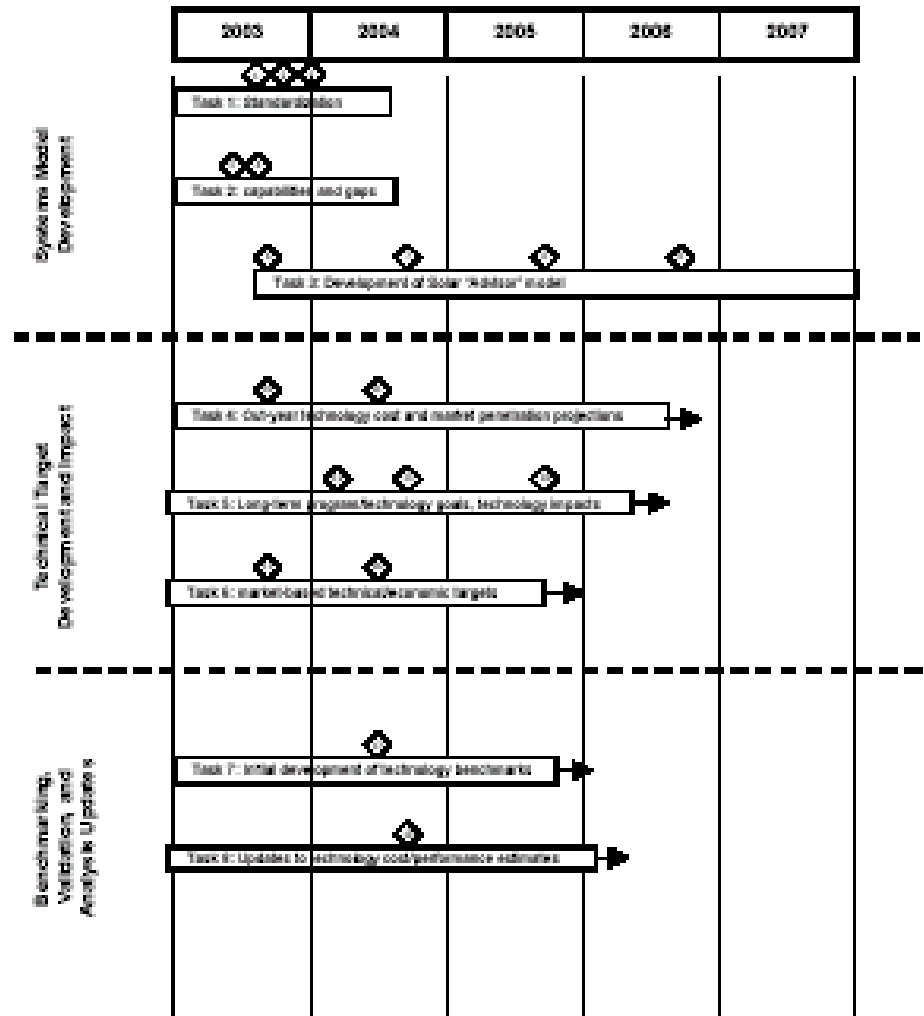
3.0 Systems Driven Approach

Table 3-1. Tasks for Systems-Driven Approach Development and Implementation

Task	Title	Barriers
I	Systems Model Development	
1	Standardization of assumptions and requirements <ul style="list-style-type: none">• Develop standard technology configurations• Develop technology benchmark input requirements• Develop standard financial/economic assumptions for baseline configurations	E,D
2	Identification of analysis capabilities and gaps <ul style="list-style-type: none">• Identify existing program/technology analysis capabilities• Identify existing or recommend development of new market-based systems models• Identify solar resource data requirements necessary to support SDA systems-analysis efforts	A
3	Development of Solar “ADVISOR” model <ul style="list-style-type: none">• Select candidate market(s) for near-term development of analysis tool• Develop analysis tools for remaining markets identified in the Solar Program Multi-Year Technical Plan.• Develop integrated Solar “ADVISOR” model based on integration of market-based tools	A



3.0 Systems Driven Approach



Legend



Milestones

1. Develop standard technology configurations
2. Develop technology benchmark input requirements
3. Develop standard technoeconomic assumptions for baseline configurations
4. Identify existing program/technology analysis capabilities
5. Identify existing or recommend development of new market-based systems analysis platforms
6. Select candidate markets for near-term development of integrated analysis platforms
7. Demonstrate beta version of 1-2 integrated solar analysis platforms for selected markets
8. Demonstrate beta versions of integrated solar analysis platforms for remaining market sectors
9. Demonstrate integrated analysis platforms for integrated market sectors
10. Identify out-year technology cost projections based on existing program/technology documents (roadmaps, program plans, etc. .)
11. Conduct rigorous due-diligence (ie review of out-year projections (not including thought-leaders)
12. Align program/technology goals with EERE and National goals and interests (i.e. conservation, infrastructure, energy supply, environment, security)
13. Complete initial analysis estimating long-term benefits that are aligned with National goals and interests
14. Complete trade-off studies identifying highest impact technologies for each market sector
15. Identify high-level market-specific technoeconomic measures of success for each technology (i.e. LCCO, payback, flat cost)
16. Complete development of initial system level technoeconomic targets for each high-level MOI
17. Document cost, performance, and reliability (PVO) benchmarks for each COBET technology based on standardized assumptions
18. Define parameters of program-wide cost, performance, and reliability data collection requirements



General Outline

1.0 Technology Systems Status

2.0 Technology and Component Goals and Objectives

3.0 Key Technical Challenges

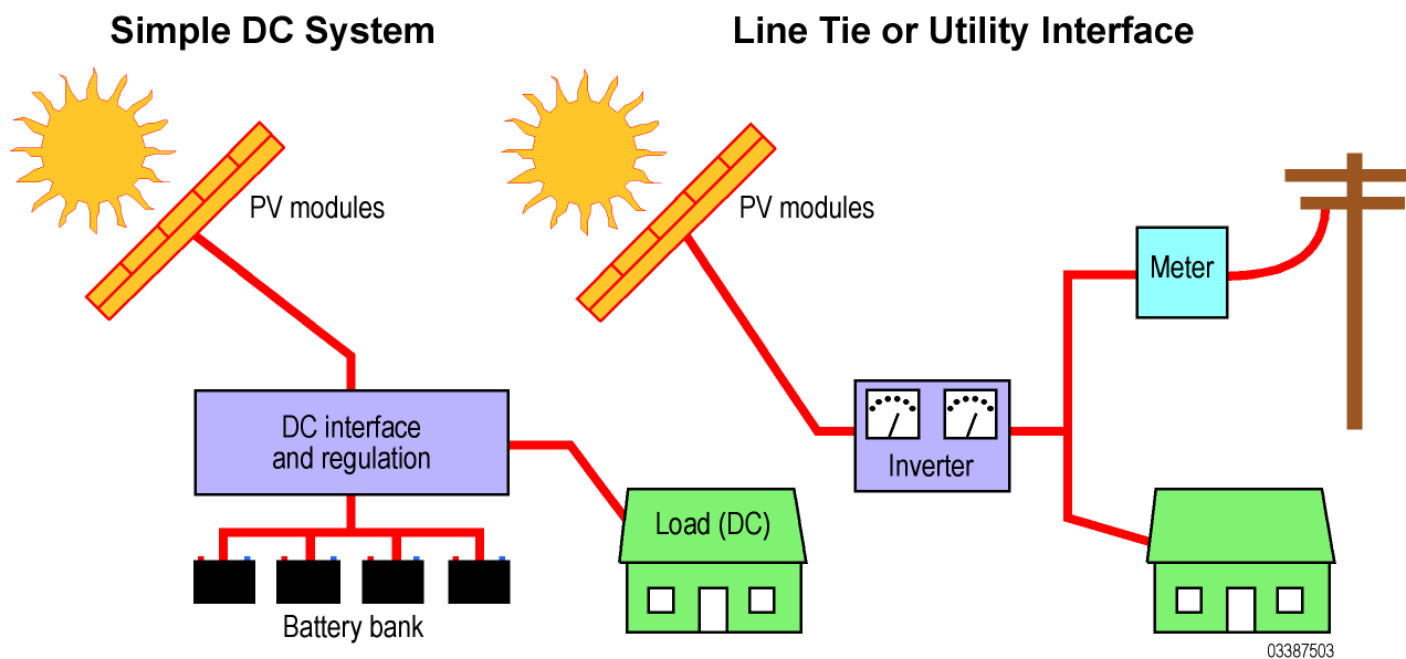
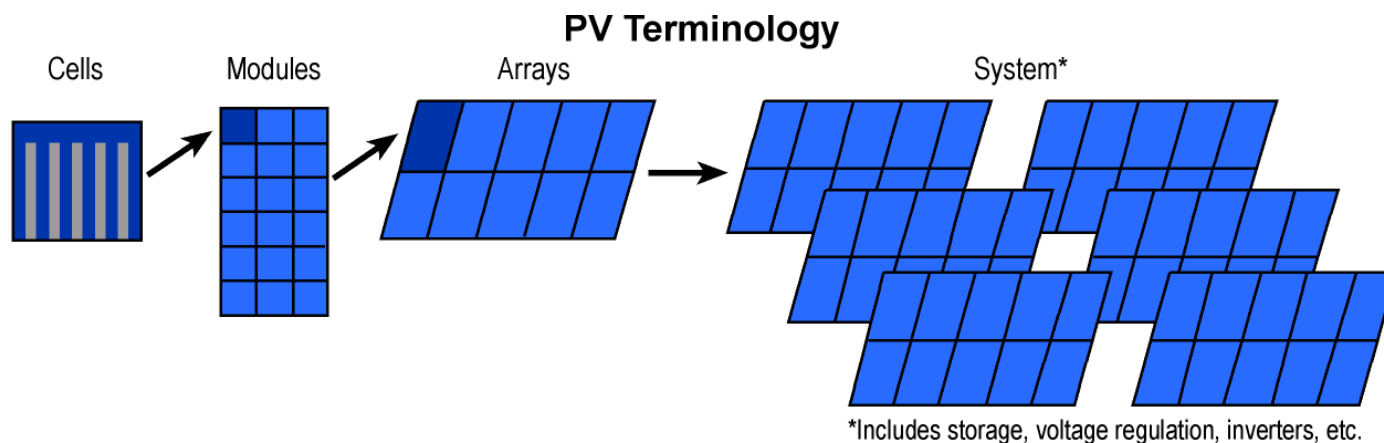
4.0 Technical Barriers

5.0 Technical Approach and Tasks

6.0 Schedule and Milestones



4.1.1 Photovoltaic Systems





4.1.1 Photovoltaic Systems

Goals:

Assist industry in developing PV systems that can provide quality performance and reliability at acceptable costs to the consumers.

Acceptable costs are determined by a number of factors and will be fine-tuned as part of the continuing analysis, target setting, and validation conducted within the context of the ongoing systems-driven approach.



4.1.1 Photovoltaic Systems

Table 4.1.1-2. Targets for Flat-Plate PV Systems in Residential Applications

Tasks for Flat Plate PV Modules (2–3-kW grid-tied systems)

1. Basic Science
2. Crystalline Silicon: cell and device improvements
3. Crystalline Silicon module improvements
4. Thin Films and High Performance: materials and device improvements
5. Thin Films: module improvements
6. Modules: cost-cutting activities

7. Systems Analysis
8. System Benchmarking and Validation
9. PV System Performance and Standards
10. PV Technology Adoption
11. Inverter Testing and Industry Support
12. High-Reliability Inverter Initiative
13. Inverter R&D 5-year Plan
14. Charge Controller and Battery Improvements

System Element	Units	2003	2007	2020
Design				
Module Price	\$/W _{dc}	4.00	2.50	1.00–1.50
Direct cost/power	\$/W _p	3.00	1.65	0.33–0.50
Conversion efficiency	%	14	16	19–20
Direct cost/area	\$/m ²	420	15	50–100
Inverter Price				
DC-AC conversion efficiency	%	94	96	97
Replacement	Years	5	10	20
Other BOS				
Installation	\$/W _{ac}	2.45	1.50	0.50
INSTALLED SYSTEM PRICE	\$/W _{ac}	6.25–9.46*	3.25	0.30–1.00
System Efficiency	%	11.5	14	16
Life	Years	20	20	30
Degradation	%/Yr	1–2	1–2	1
O&M cost	\$/kWh _{ac}	0.08	0.02	0.005
LEVELIZED ENERGY COST	\$/kWh _{ac}	0.25–0.40*	0.22	0.8–0.10

Considerations:

LEC is cost to consumer.

2003 numbers taken from example of Figure 4.1.1-3.

LEC is dependent on solar resource (2000 kWh/m²/yr assumed here).

2003 data assume retrofit market; 2007 and 2020 are for new construction.

O&M primarily based on one inverter replacement every 5 years for 2003 figures; every 10 years for 2010 and 2020 figures.

*The ranges reflect the variability in calculations including various incentives and financing assumptions. LECs have been reported previously for year 2000 with incentives included.



4.1.2 Concentrator Photovoltaic Systems

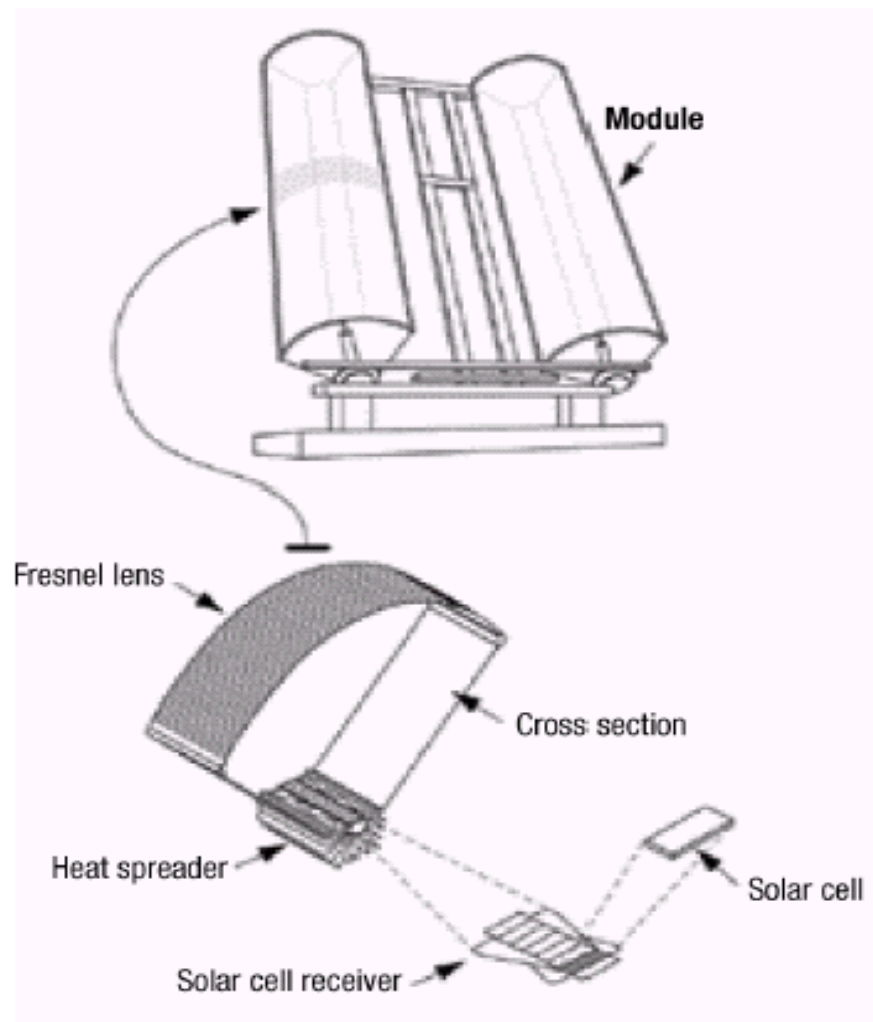


Figure 4.1.2-3. Schematic of a linear-focus Fresnel lens concentrator PV system.

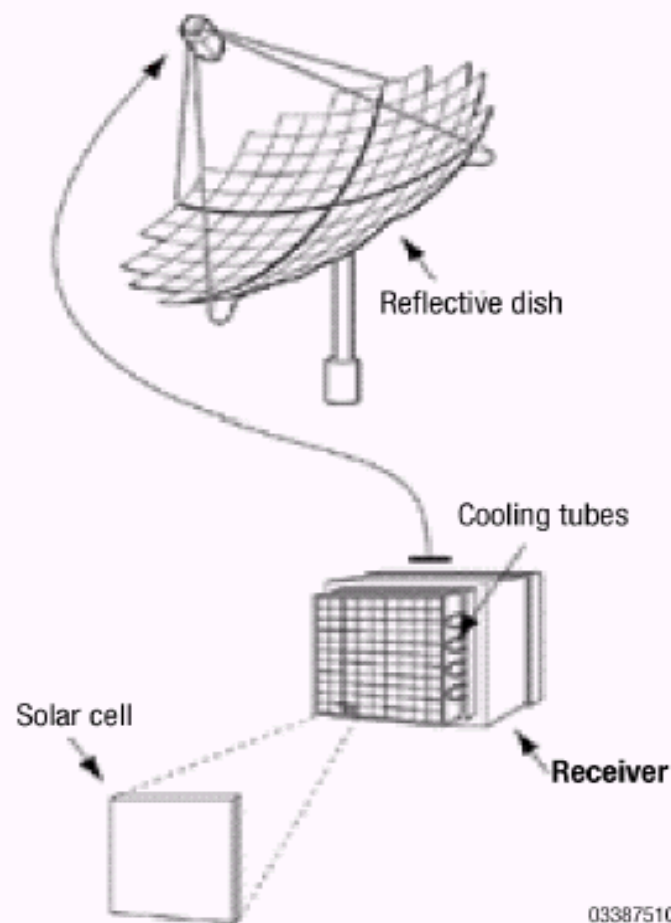


Figure 4.1.2-4. Schematic of a point-focus dish concentrator PV system.

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4.1.2 Concentrator Photovoltaic Systems

Goals:

Develop viable concentrator photovoltaic technologies for application in a wide range of electrical markets, particularly for the distributed generation and larger bulk electric utility markets.

The target electricity cost is 4 to 6 cents/kWh by 2020.



4.1.2 Concentrator Photovoltaic Systems

Table 4.1.2-1. Technical Targets for CPV Technologies

System Element	Units	2003 (baseline)	2007	2025
Solar resource	kWh/m ² -yr	2400	2400	2400
Plant size	MW	1	10	80
(Production) solar cell efficiency	%	23	33	40
Optical efficiency	%	80	85	90
Cell cost per cell area	\$/cm ²	2 (silicon)	3 (III-V)	1.50 (III-V)
System efficiency	%	15	22	33
Capacity factor	%	32	32	32
CPV module cost	\$/m ²	160	90	80
Tracking cost	\$/m ²	70	35	25
Power-related balance-of-systems	\$/W _p	0.6	0.3	0.15
Area-related BOS other than land	\$/m ²	140	70	50
Indirect costs (% added to all above costs, not including land, to account for marketing and other indirect costs)	%	20	15	10
Annual O&M costs	\$/kWh-yr	.02	.01	.005
Total capital cost per AC W _p	\$/W _p	9.00	5.0	1.0

Tasks for CPV Technology R&D

1. CPV Cell Research and Development
2. CPV Receiver Research and Development
3. CPV Module Research and Development
4. System Analysis



4.2 Concentrating Solar Power Systems

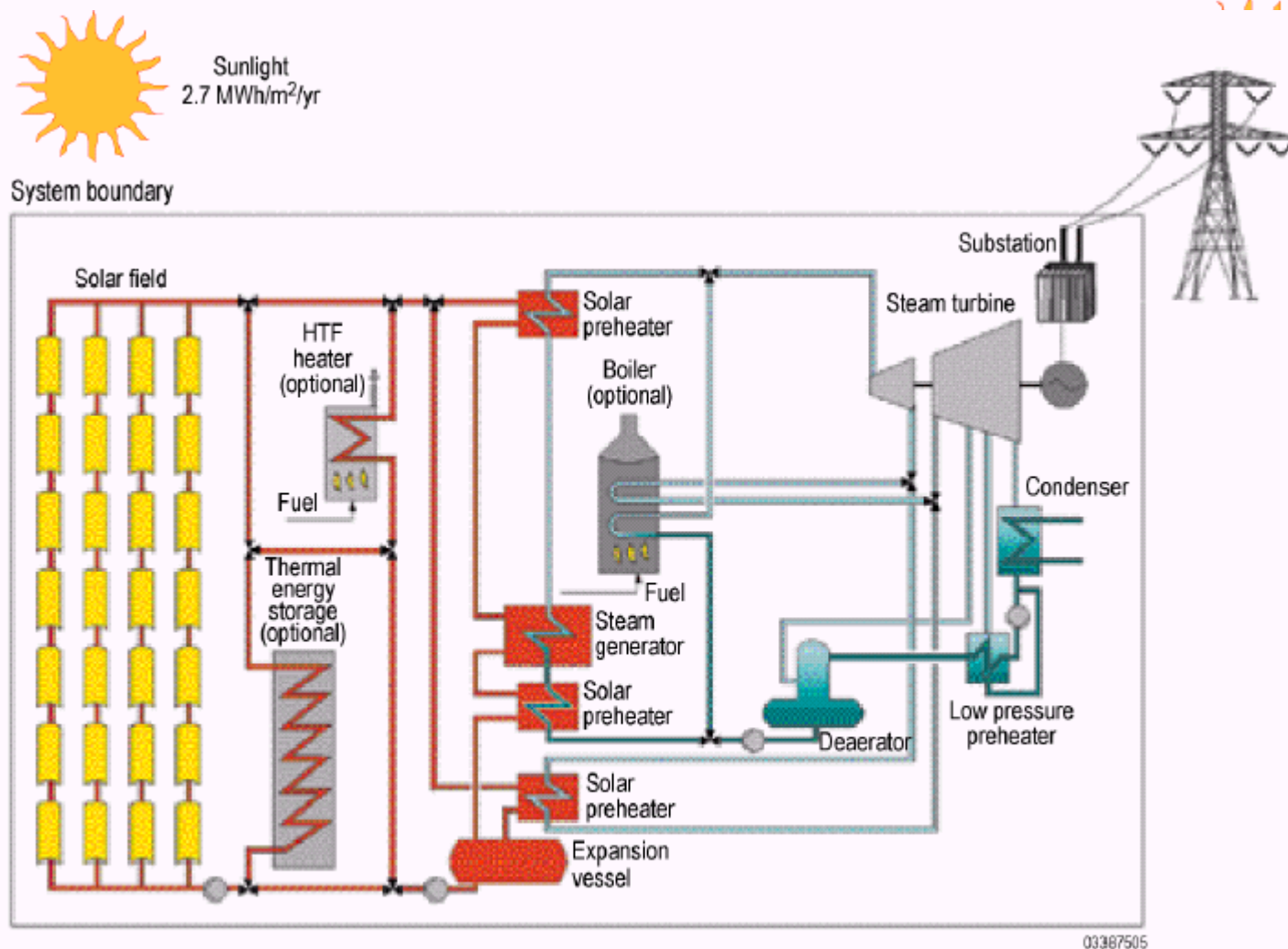


Figure 4.2-1. Schematic of a parabolic-trough system.



4.2 Concentrating Solar Power Systems

Goals:

Troughs

- Develop parabolic-trough power plant technologies capable of competing on a cost competitive basis with conventional fossil power technologies as dispatchable intermediate load generation in the wholesale bulk-power market (levelized energy cost [LEC] \$0.04 to \$0.06/kWh).

Towers

- Develop power tower technologies that will be cost competitive with conventional fossil power technologies as dispatchable intermediate-to-baseload generation in the wholesale bulk power market (\$0.04–\$0.06¢/kWh).

Dishes

- Develop dish-Stirling systems capable of competing in niche areas of distributed generation (short-term competition is diesel generators), grid support, remote and village power markets. Ultimately, bulk-power generation may be a market for these systems.



4.2 Concentrating Solar Power Systems

Tasks for Parabolic Trough

Table 4.2-1. Technical Targets: Parabolic Trough Power

(Solar-only operation at premium technology)

Table 4.2-2. Technical Targets: Power Tower

Tasks for Dish-Engine/ Converter

Technology R&D

1.

1. Perform Systems Analysis

Table 4.2-3. Technical Targets: Dishes

2.

2. Improve System Performance and Reliability

3.

3. Develop and Test Advanced Components

4.

4. Promote/Support Deployment by Industry

Tasks

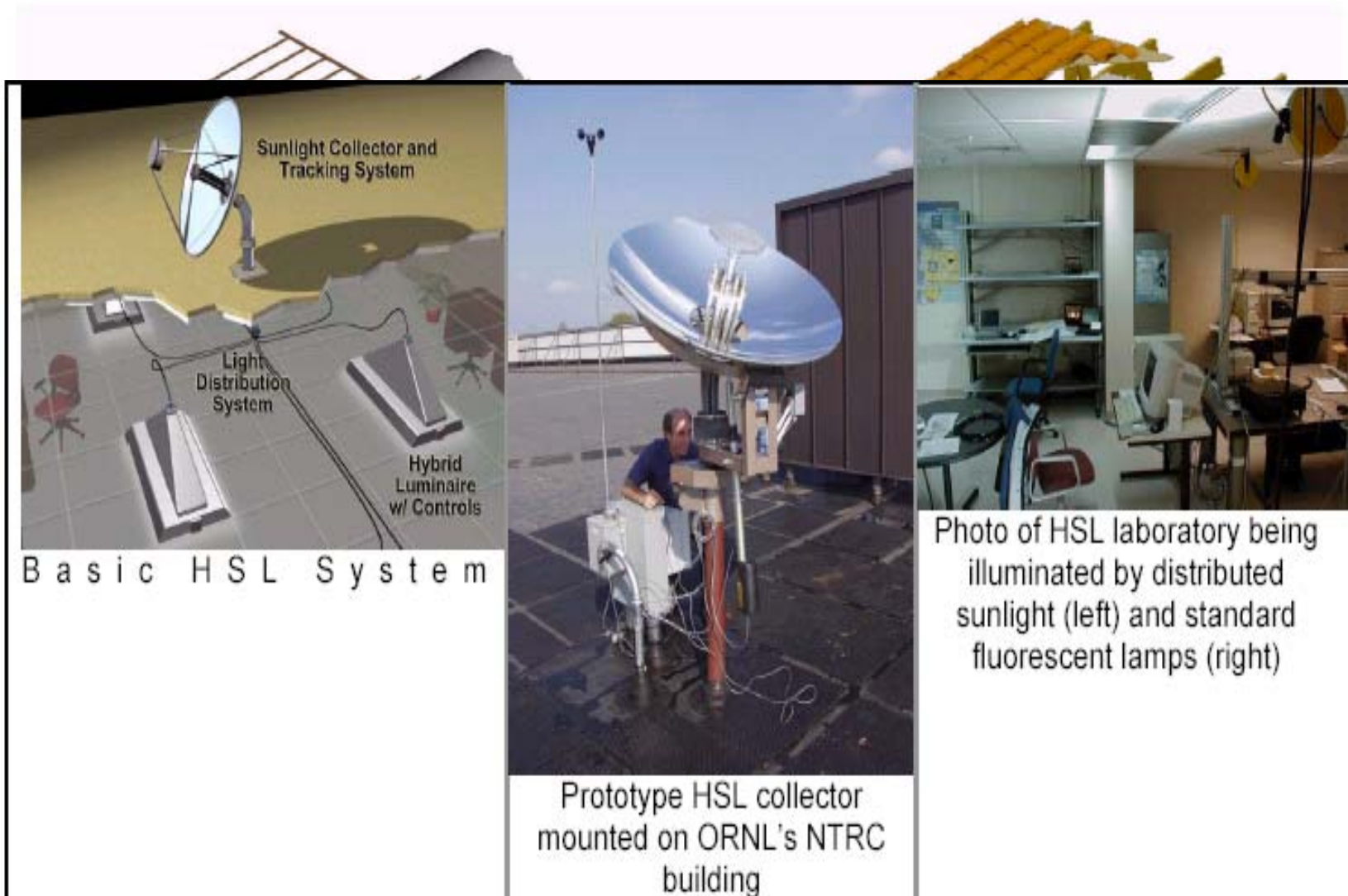
Plant Characteristics		Units	Calendar year		
			2003	2007	2025
Solar Resource: Daggett, CA		kWh/m ² -yr	2800	2800	2800
Solar Collector					
Solar Aperture Area	m ²	91	91	88	88
Projected Glass Area	m ²	88	88	85	85
Reflectivity		0.92	0.94	0.95	0.95
Intercept Factor		0.95	0.97	0.99	0.99
Concentrator Weight	Kg/m ²	75	65	30	30
Power Conversion Unit					
Receiver Type		DIR	DIR	ADV*	ADV*
Receiver Efficiency		0.90	0.90	0.95	0.95
Engine Type		KSE	KSE	ADV	ADV
Engine Efficiency		0.32	0.35	0.42	0.42
System Performance Parameters					
Capacity Factor					
Annual Solar Energy Production	kWhrs/m ²	575	627	754	754
Annual Total Energy Production	KWhrs/m ²	575	627	1095	1095
Annual Solar Efficiency Net		0.20	0.23	0.26	0.26
Annual Capacity Factor		0.24	0.24	0.50	0.50
Levelized Energy Cost	\$/KWhr	0.40	0.20	0.06	0.06

Considerations:

Hybrid receiver in 2025.



4.3 Solar Heating and Lighting





4.3 Solar Heating and Lighting

Goals:

- Develop low-cost passive solar water heaters for warm climates that will be cost-competitive with conventional technologies, with levelized energy cost (LEC) of 4-6¢/kWh. This represents a 25%–50% reduction.
- Develop low-cost active solar systems for solar water heating in cold climates and for combined building heating and cooling that have LEC of 6¢/kWh. This represents a 50%– 70% cost reduction, depending on application.
- Develop a low-cost hybrid solar lighting system that has LEC of 12¢/kWh, a reduction of 70% from the current cost estimate of the first system.



4.3 Solar Heating and Lighting

Tasks for Passive Solar Water Heating for Warm Climates

1. Durability
2. Building Codes
3. Manufacturing

Tasks for Active Cold Climate Water Heating and Active Solar Combined Heating and Cooling

1. Collector
2. Storage
3. Balance of System
4. System Integration

Tasks for Hybrid Solar Lighting

1. Collector
2. Fiber Optics
3. Balance of System
4. System Integration and Analysis

Table 4.3-2. Technical Targets^a — Active Solar

Table 4.3-3 Technical Targets — Hybrid Solar Lighting

Characteristics	2003 status	2007 goal
Energy displacement efficiency	52%–250%	70%–315%
Projected installed \$/W _p	\$3.00/W _p	\$2.00/W _p
Projected payback period (Sun Belt)	20 years	4 years
Projected relative lifecycle cost	\$20,000	\$5,000
Projected net savings	\$0.41/kWh	\$0.12/kWh
Projected system collector area	\$10,000/m ²	2,000/m ²
Delivered lumens/m ² collector area	40,000 lum	50,000 lum
Projected cost of delivered lumens (peak)	\$0.16/lum _p	\$0.035/lum _p

Note: Energy displacement efficiency is the amount of electrical power displaced per unit incident

a: Collector solar power available.

b: Typical collector area (m²) required in a southwest Sun Belt climate, assuming 6000 hours, 0.75, with 1000 = 0.6 kWh/m² day, at tilt of (lat-15°).

d: Glazed system: space heating and DHW only, no cooling.

e: Un glazed system with space heating, DHW, and space cooling (radiative/convective heat rejection at night); ~6% net heating efficiency increased to 8% to account for the cooling savings.

f: Marketing cost taken as 25% of builder cost for SWH, and 15% of cost for space htg/clg system.



4.4 New Concepts

Beyond the Horizon and Future Generation Photovoltaics:

- *Organic Solar Cells*
- *Dye-Sensitized Solar Cells*
- *Nanotechnology Solar Cells*
- *Third-Generation Technology*

Advanced Building Integrated Concepts:

- *AC Building Block*
- *PV/Thermal Hybrid*

Advanced Solar Conversion:

- *Solar-Thermal Hydrogen*
- *Direct Conversion*
- *Thermochemical Transport and Storage*

***None of these activities are presently along any of the Program's critical paths.



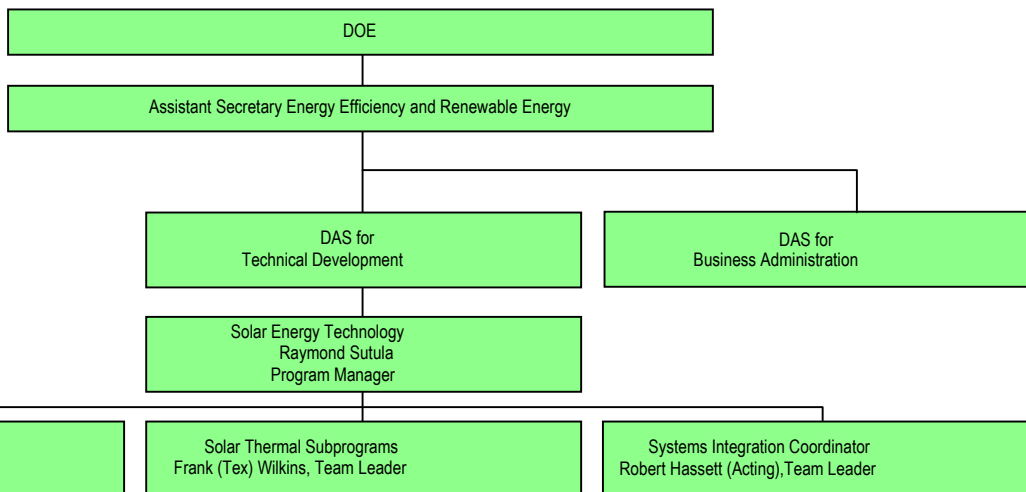
5.0 Managing the Solar Energy Program

- Overall Metric is Levelized cost of energy (LCOE)
- Long-Term goals
 - Photovoltaics @ \$0.06/kWh (\$1/watt)
 - Concentrating Solar Power @ \$0.04-0.06/kWh (50% capacity factor)
 - Solar Hot Water @ \$0.04-0.06/kWh (\$1,300.00 installed)

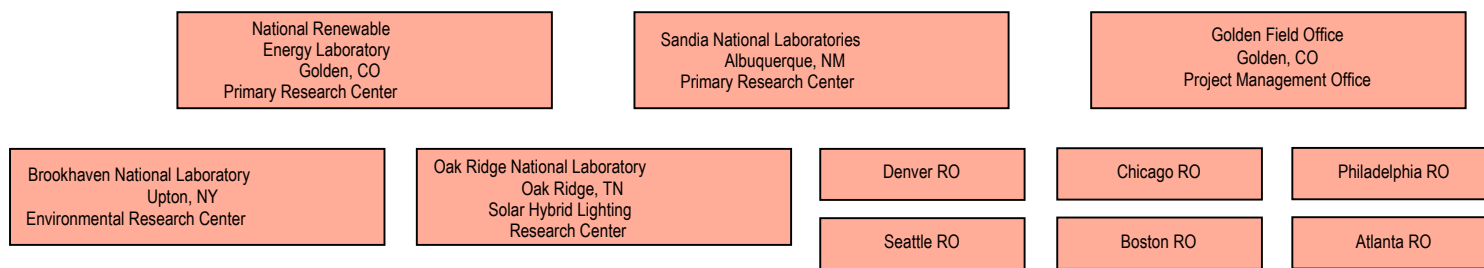


5.0 Managing the Solar Energy Program

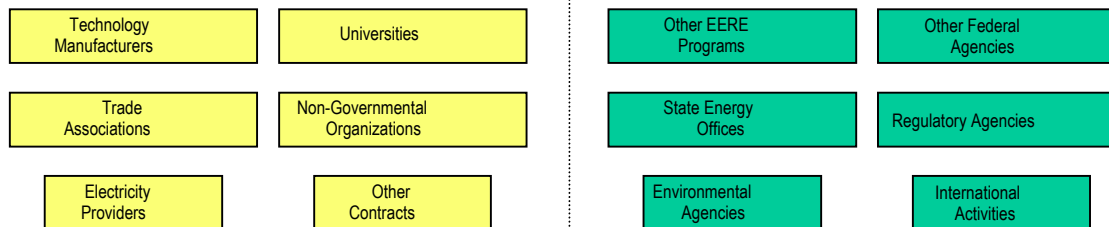
DOE Headquarters (Executive Management)



Field Operations
(Operations Mgmt)



Program Partners



Industry

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Acknowledgements

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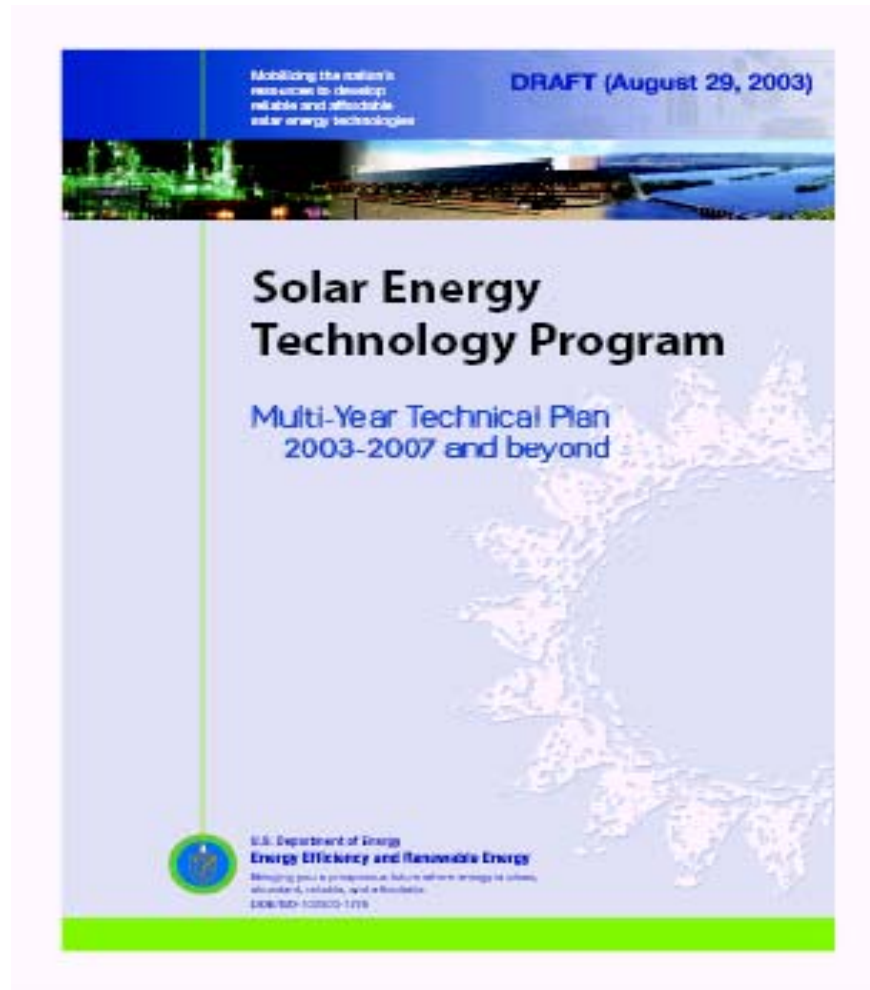
Nancy Wells

Ken Zweibel



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Solar MYTP Available



<http://www.nrel.gov/extranet/techplan/techplan.html>